Photovoltaics (PV)

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PHIUS
Passive House Institute US

Session Learning Objectives:

1. Understand PV system options and benefits,
2. Understand what conditions are needed to minimize installation costs and maximize electricity production,
3. Be able to use a sizing tools for estimating system size, costs, and energy production,
4. Understand what PV Ready design means
5. Be able to integrate PV Ready design principles in their PHIUS-certified buildings.

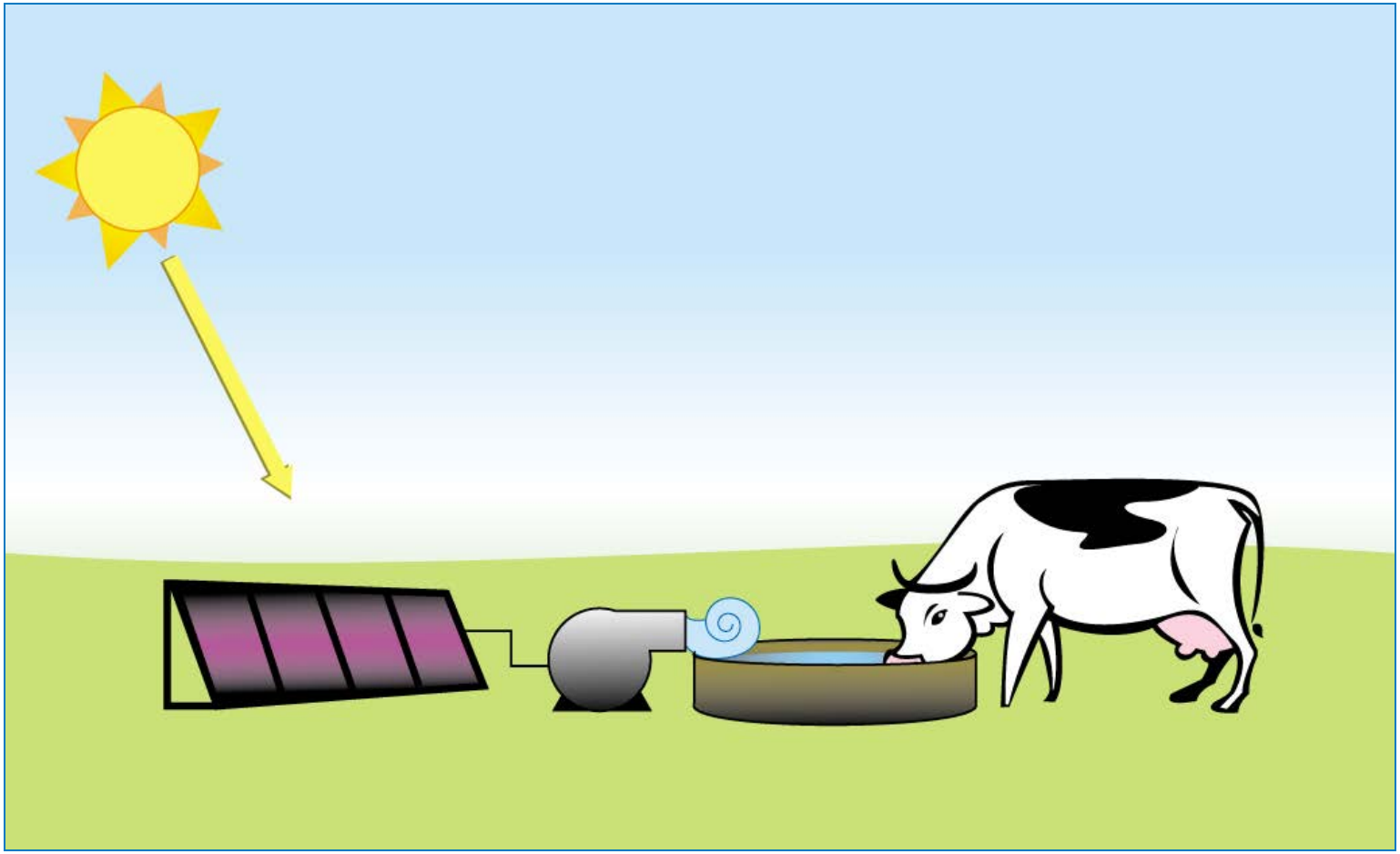
Van Geet Home

Van Geet Home

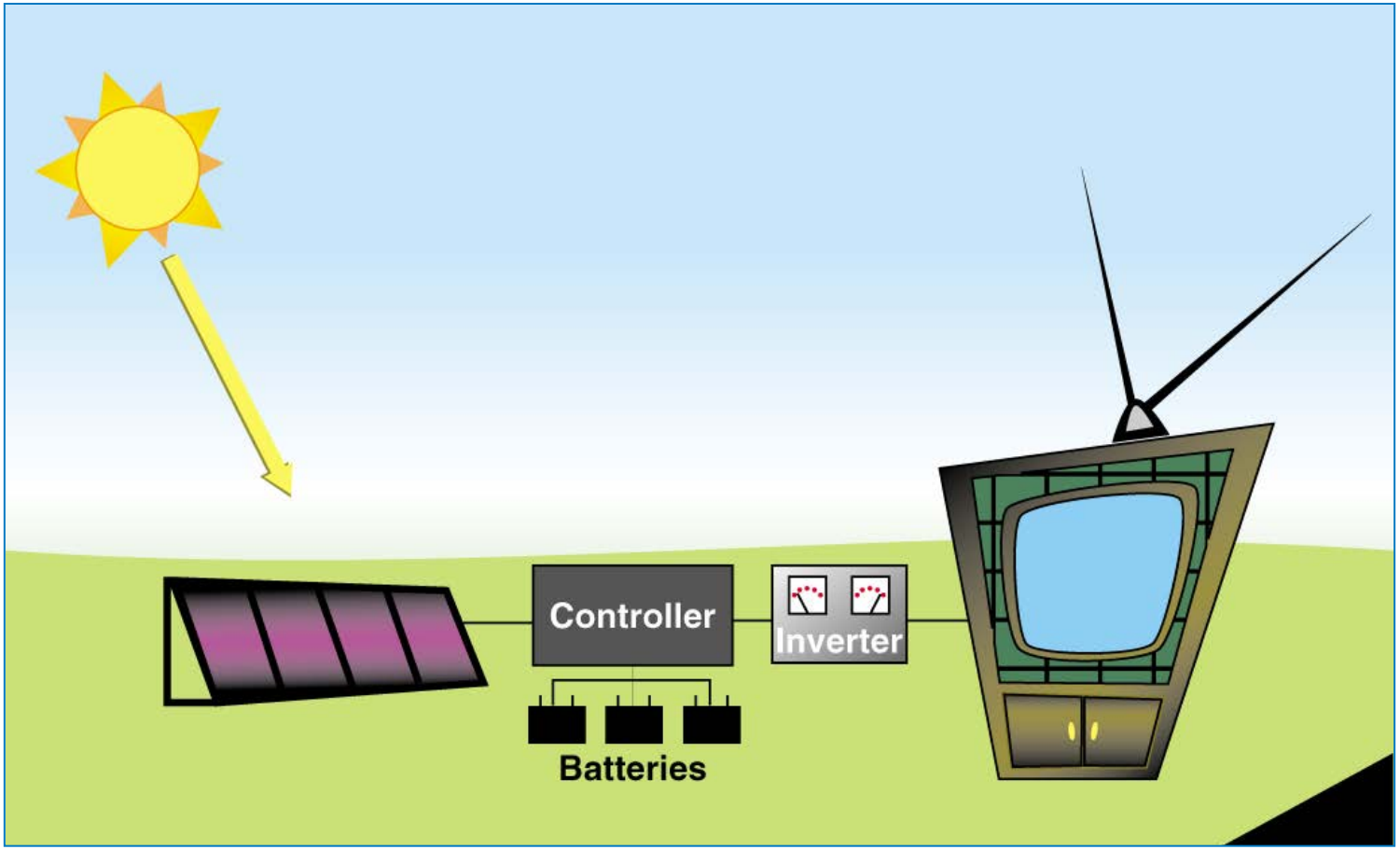
http://www.nrel.gov/docs/fy04osti/32765.pdf

- 9300 ft
- 9600 HDD
- 0 CDD
- 3000 sqft.
- Off grid high mass passive solar
- Average ANNUAL total energy = 150 gal propane
- ½ cord firewood
- 1.2 kW PV
- ASHRAE 2001 1st Place Technology Award winner

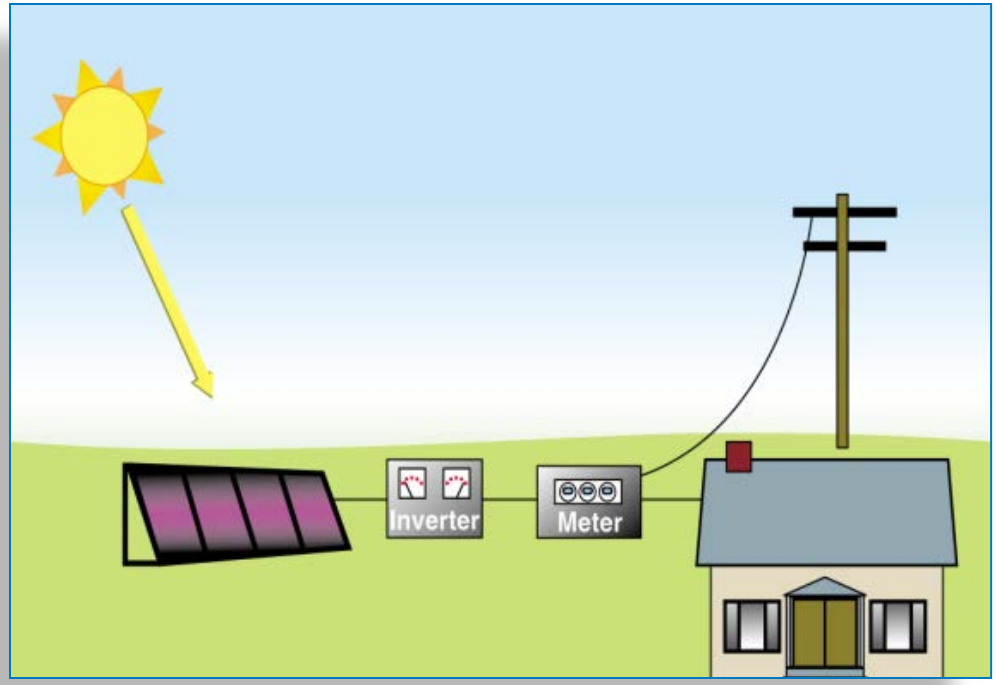
Simple Direct Drive PV System



AC PV System with Inverter

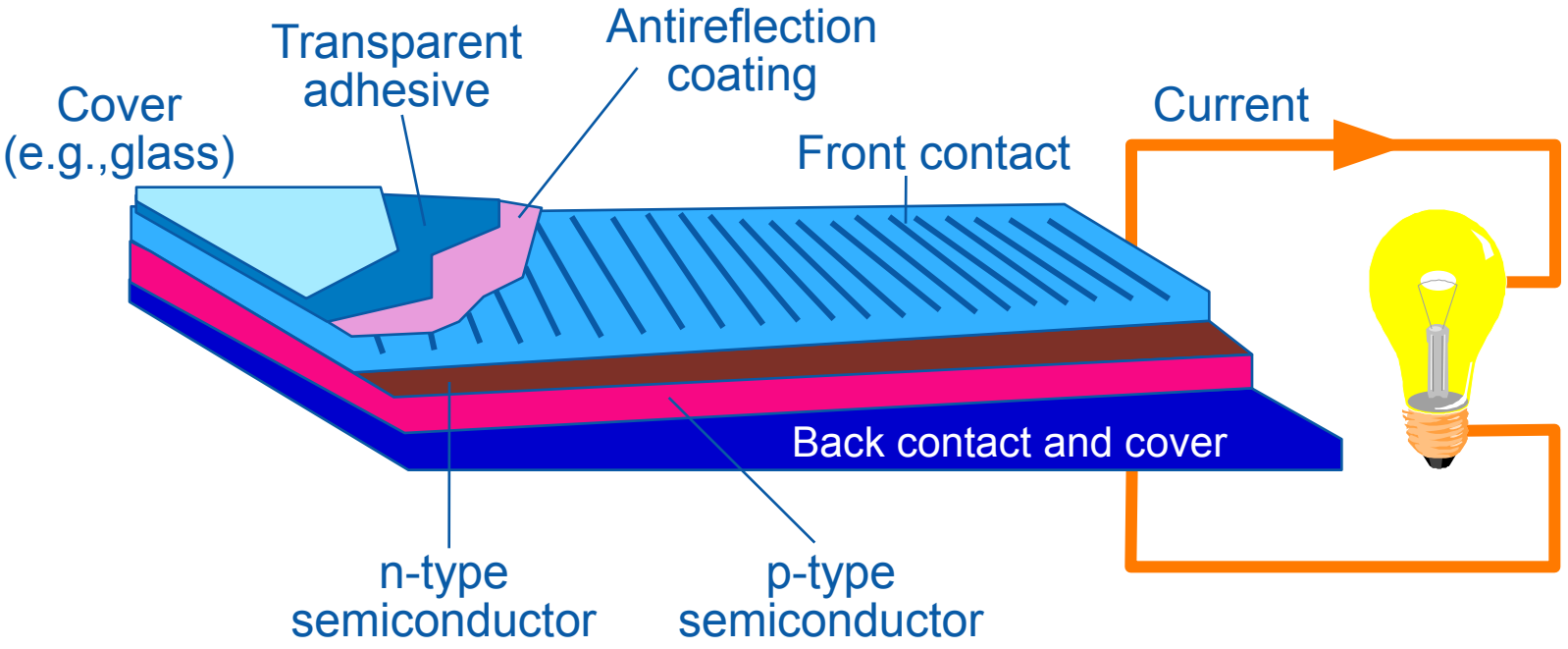


PV Technology Overview



- Direct conversion of sunlight into DC electricity
- DC converted to AC by inverter
- Solid-state electronics, no-moving parts
- High reliability, warranties of 20 years or more
- PV modules are wired in series and parallel to meet voltage and current requirements

Photovoltaic Cell Structure

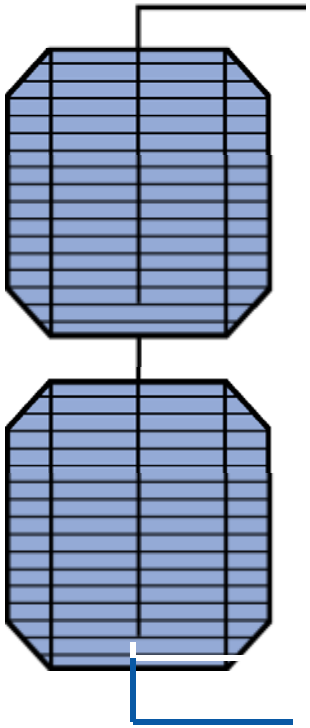


$$\text{Solar cell efficiency (\%)} = \frac{\text{Power out (W)} \times 100\%}{\text{Area (m}^2\text{)} \times 1000\ \text{W/m}^2}$$

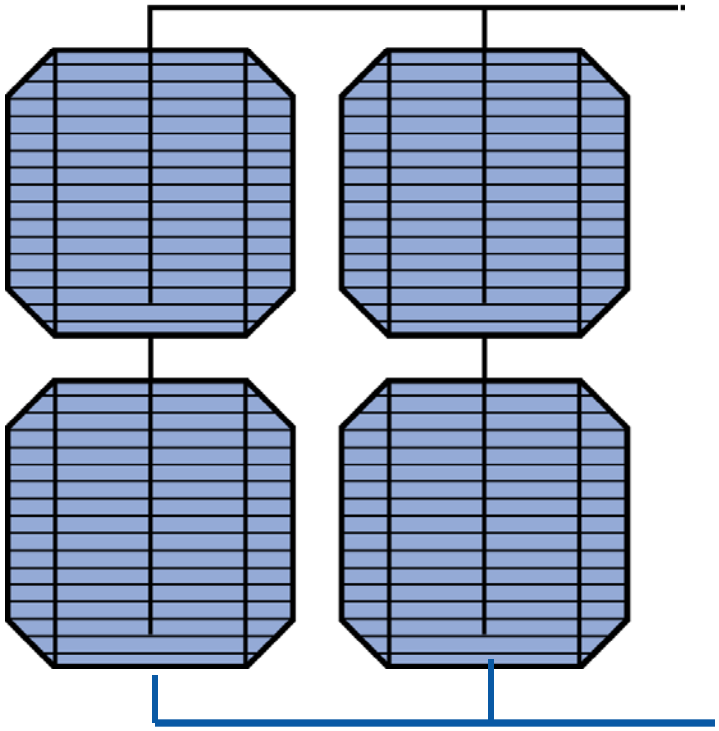
10% efficiency = 100 W/m^2 or about 10 W/ft^2 PANEL area

PV Cells

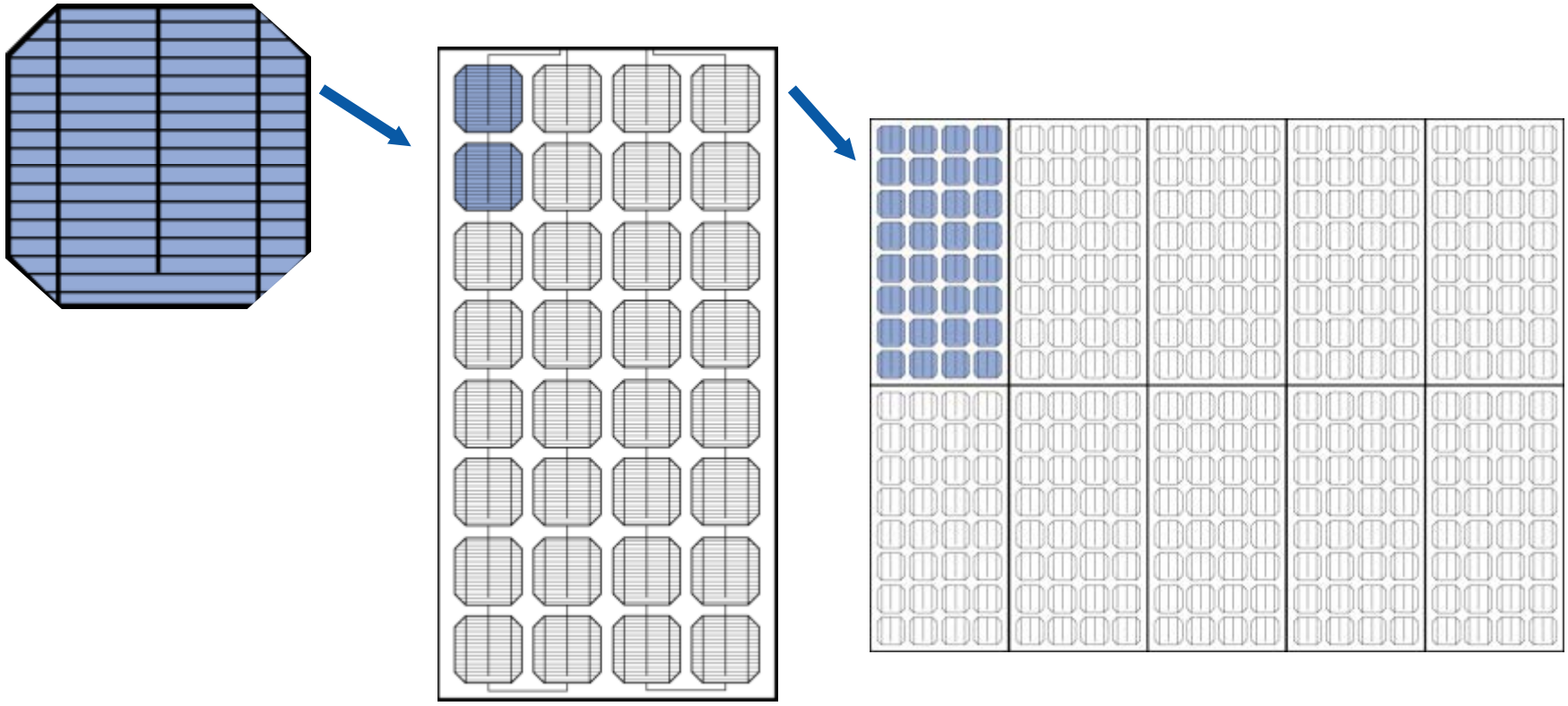
PV Cells are wired in series to increase voltage...



and in parallel to increase current



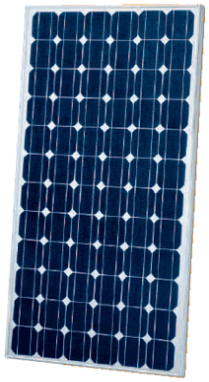
PV is Modular

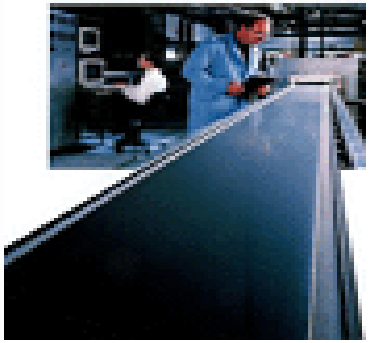


Cells are assembled into ***Modules***... and modules into arrays.

Photovoltaics

Single Crystal * Multi-Crystal * Thin Film * Cadmium Telluride * CIGS





Efficiencies:

14 to 23% 13 to 17% 6 to 11% 10% to 11% 12% to 14%

Building-Integrated Photovoltaics

Glazing

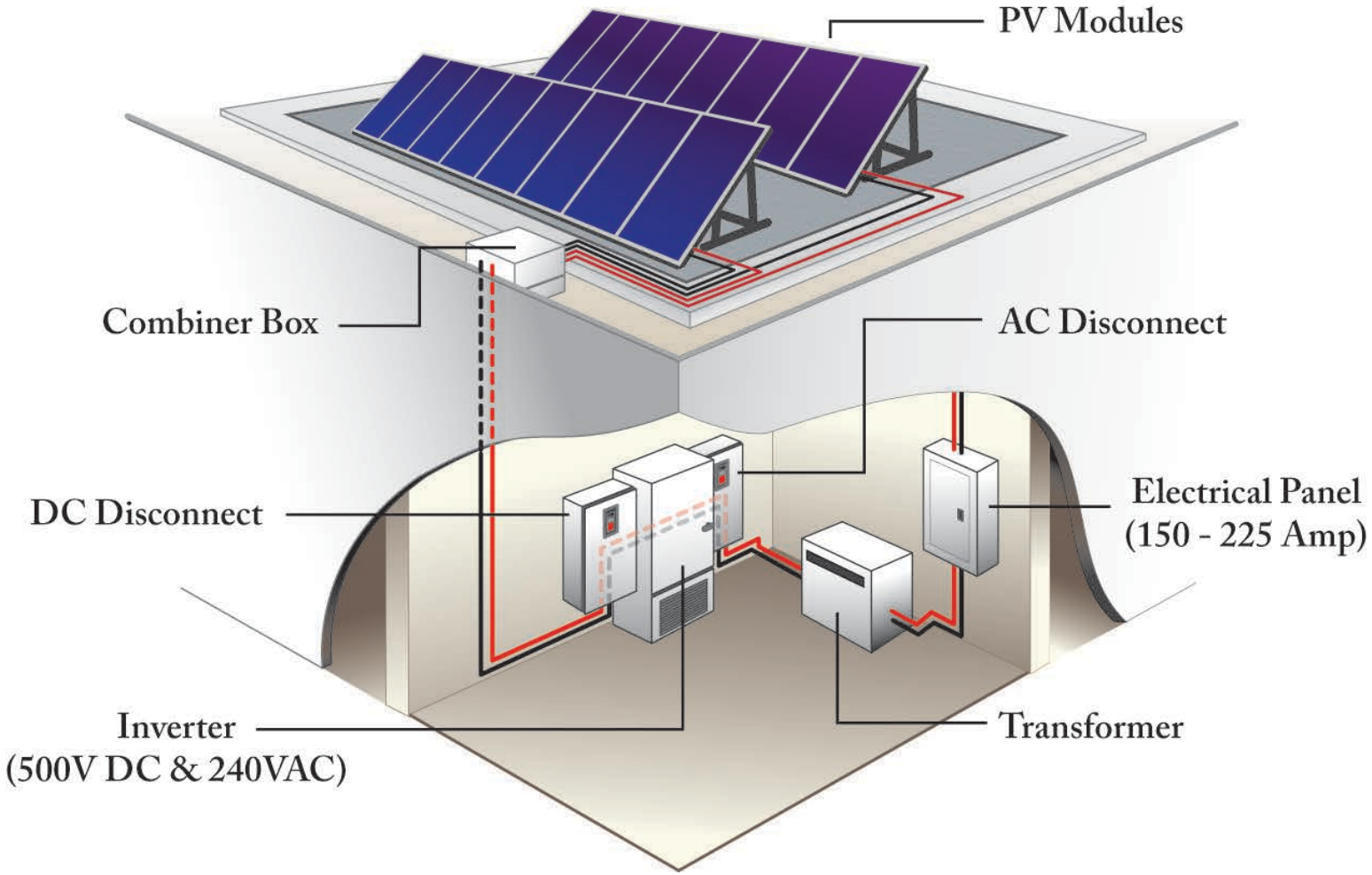
Shingles

Baseline – RE = 0

Standing Seam

Single-Ply

Photovoltaics System (grid connected)

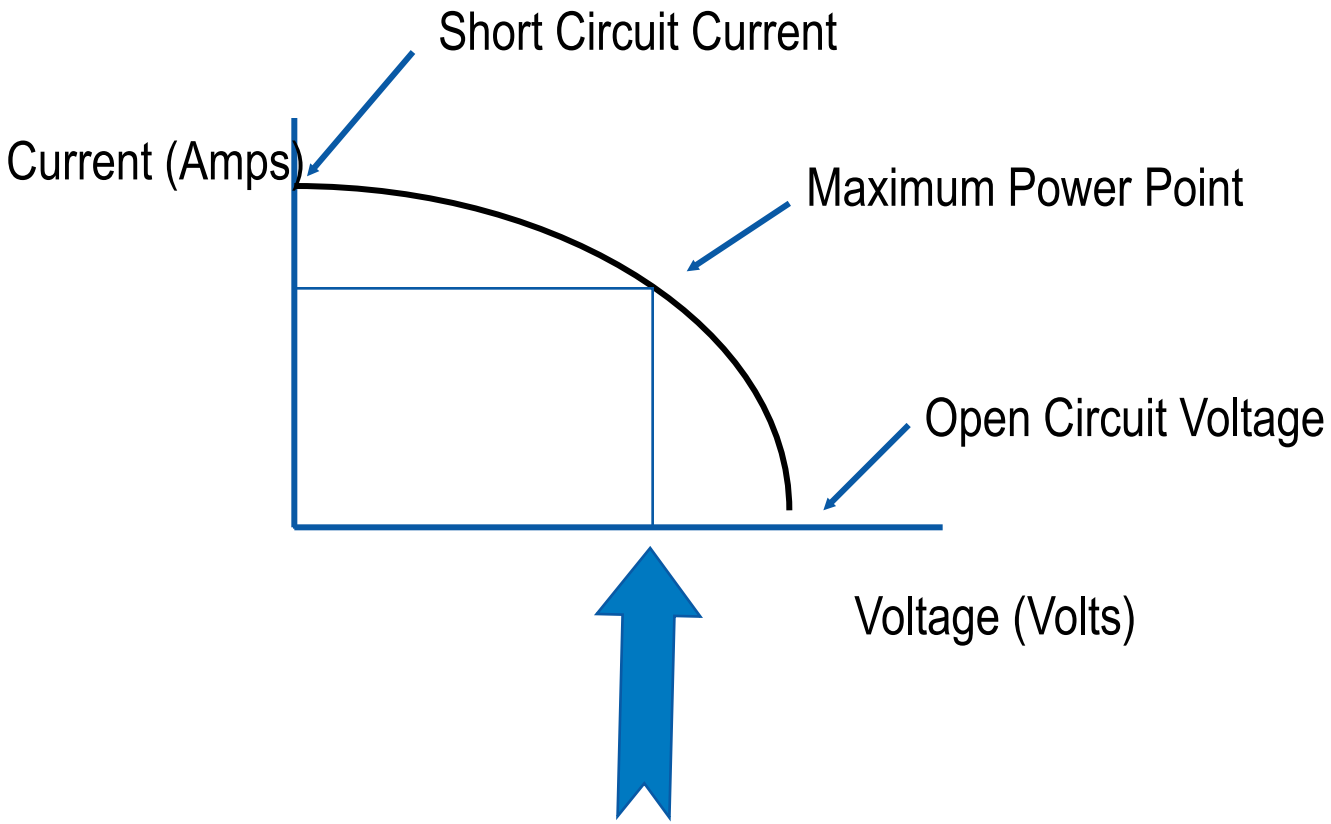


Total Area Required for PV

- Varies by technology, tilt, and location
- Roof mount - sloped roof, flush-mounted power densities of 11 DC-watt (W)/square foot (ft^2) crystalline
- Flat roof, slope panel = 8 DC-W/ft^2
- Ground mount:

System Type	Fixed Tilt Energy Density (DC-W/ft^2)	Single Axis Tracking Energy Density (DC-W/ft^2)
Crystalline Silicon	4	3.3
Thin Film	3.3	2.7
Hybrid High Efficiency	4.8	3.9

PV Cells "I-V Curve"

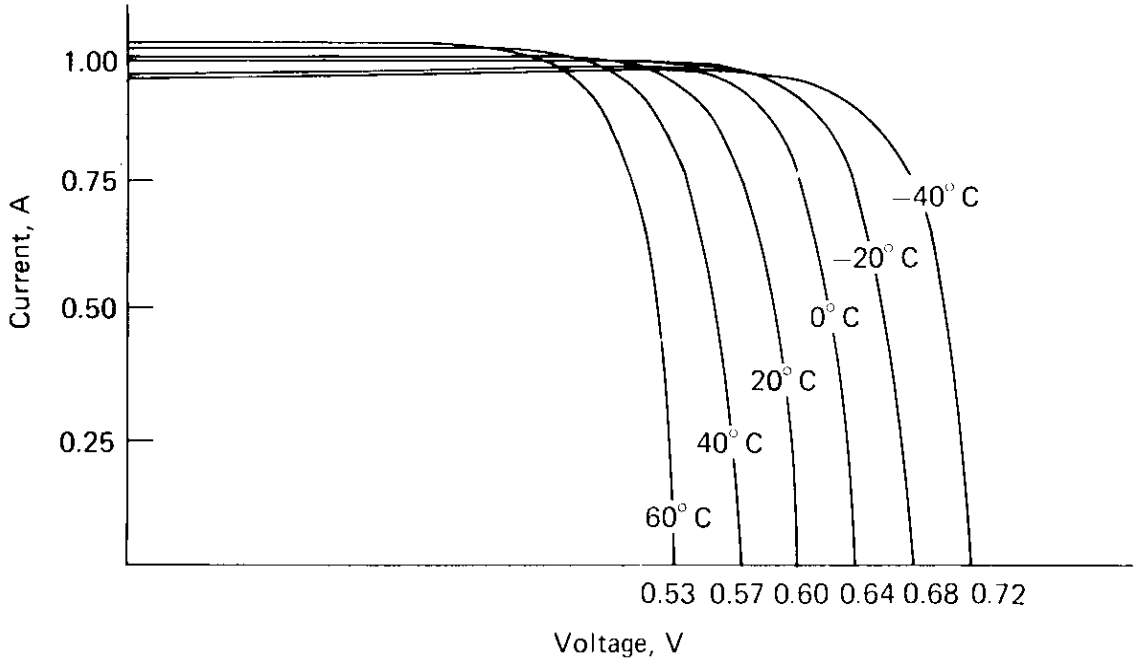


Optimal voltage changes with sunlight and temperature

IV Curve: Voltage and Temperature

Voltage (Volts) of each cell depends on the material's band gap (eV),

- Goes down slightly with increasing temperature
- Allow for airflow around PV



Changing voltage with changing temperature.

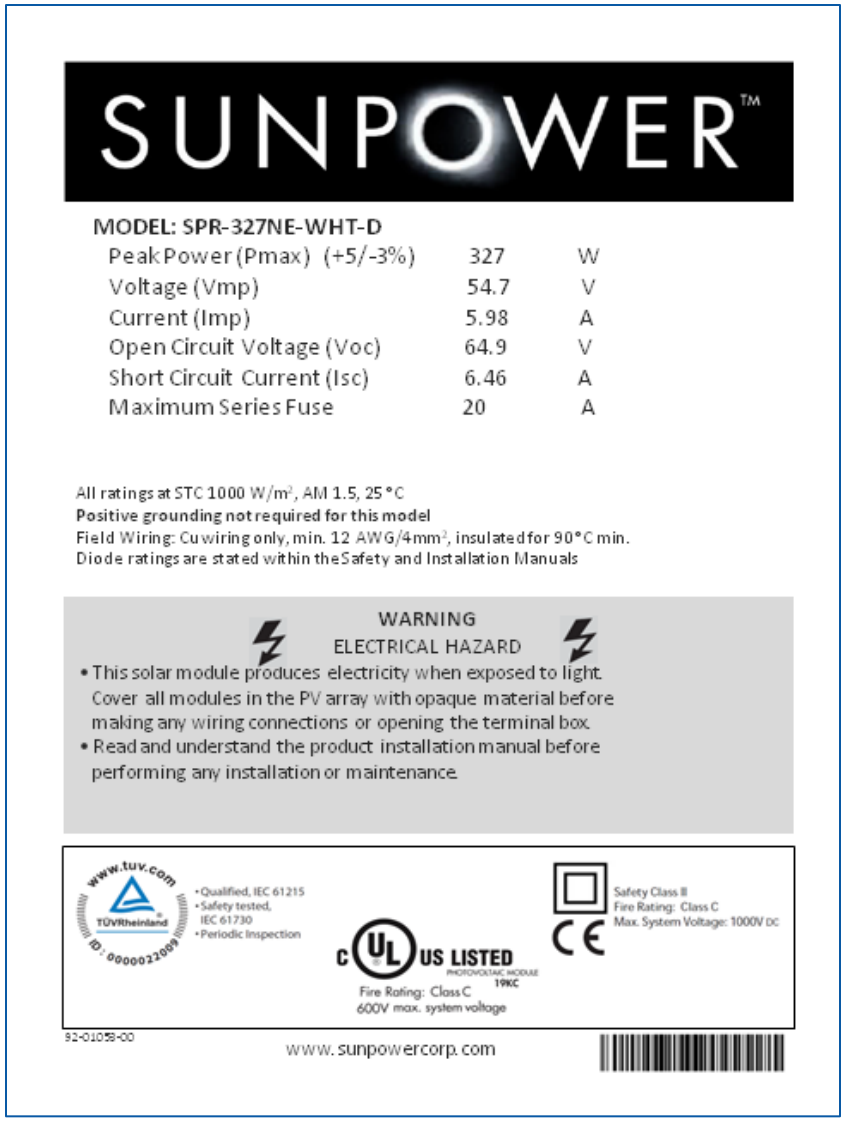
PV Module Nameplate Rating

"Rated Power" is the output of a PV module under standard reference conditions

- 1 kW/m^2 sunlight,
- 25 C ambient temperature
- 1 m/s wind speed.

ASTM E1036-96, Standard Test Method for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells

PV Module Nameplate Example



SUNPOWER™

MODEL: SPR-327NE-WHT-D

Peak Power (Pmax) (+5/-3%)	327	W
Voltage (Vmp)	54.7	V
Current (Imp)	5.98	A
Open Circuit Voltage (Voc)	64.9	V
Short Circuit Current (Isc)	6.46	A
Maximum Series Fuse	20	A

All ratings at STC 1000 W/m², AM 1.5, 25 °C
Positive grounding not required for this model
Field Wiring: Cu wiring only, min. 12 AWG/4mm², insulated for 90°C min.
Diode ratings are stated within the Safety and Installation Manuals

WARNING
ELECTRICAL HAZARD

- This solar module produces electricity when exposed to light. Cover all modules in the PV array with opaque material before making any wiring connections or opening the terminal box.
- Read and understand the product installation manual before performing any installation or maintenance.

www.tuv.com TÜVRheinland ID: 000002009
• Qualified, IEC 61215
• Safety tested, IEC 61730
• Periodic Inspection

c UL us LISTED PHOTOVOLTAIC MODULE 19KC
Fire Rating: Class C
600V max. system voltage

Safety Class II
Fire Rating: Class C
Max. System Voltage: 1000V DC

92-01058-00

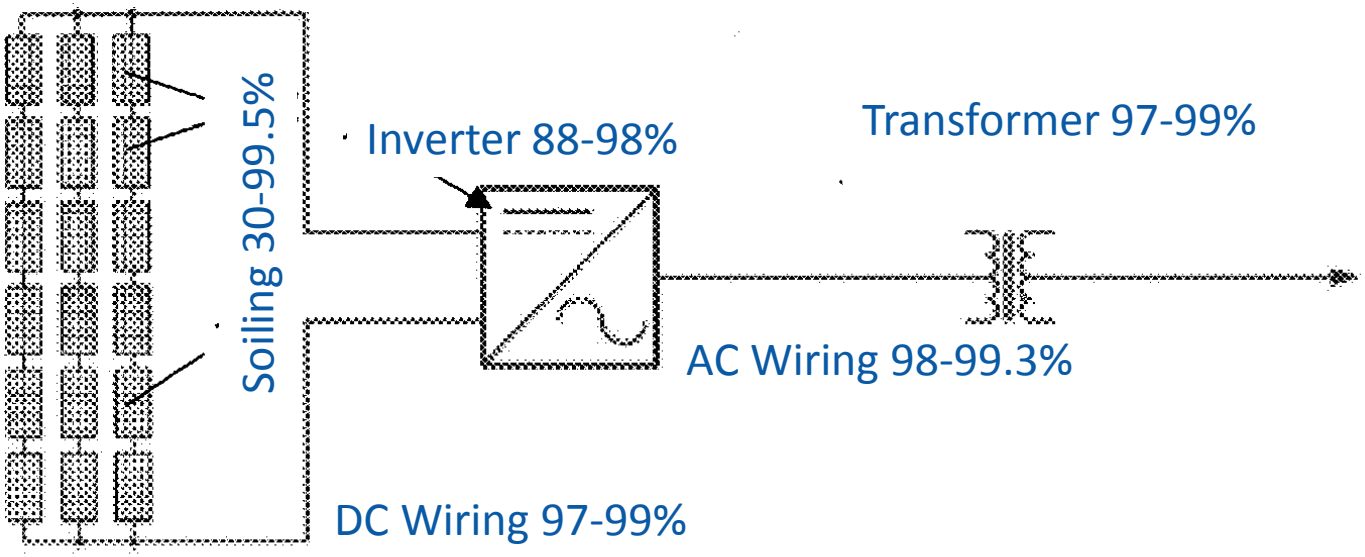
www.sunpowercorp.com

“Balance of System” Efficiency 60-82%

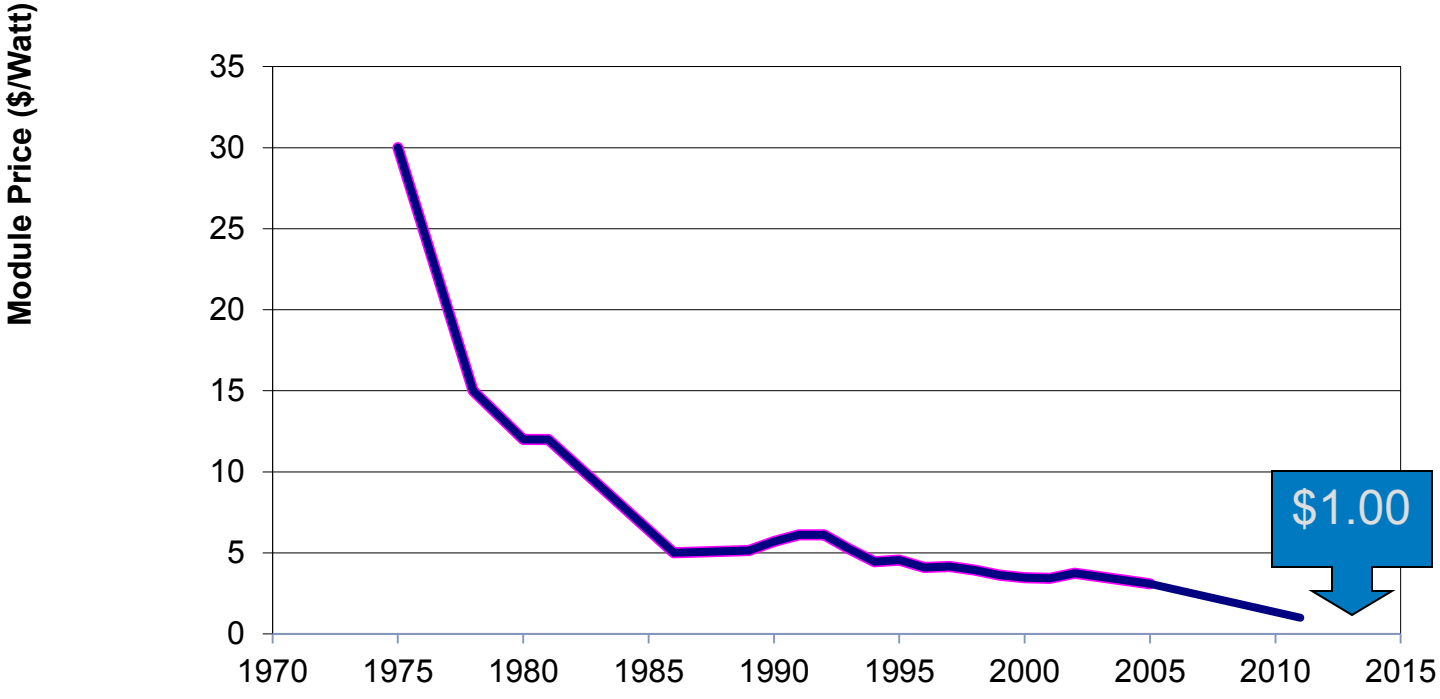
Module Efficiency 6-20%

Diodes and Connections 99-99.7%

I and V Mismatch 97-99.7%

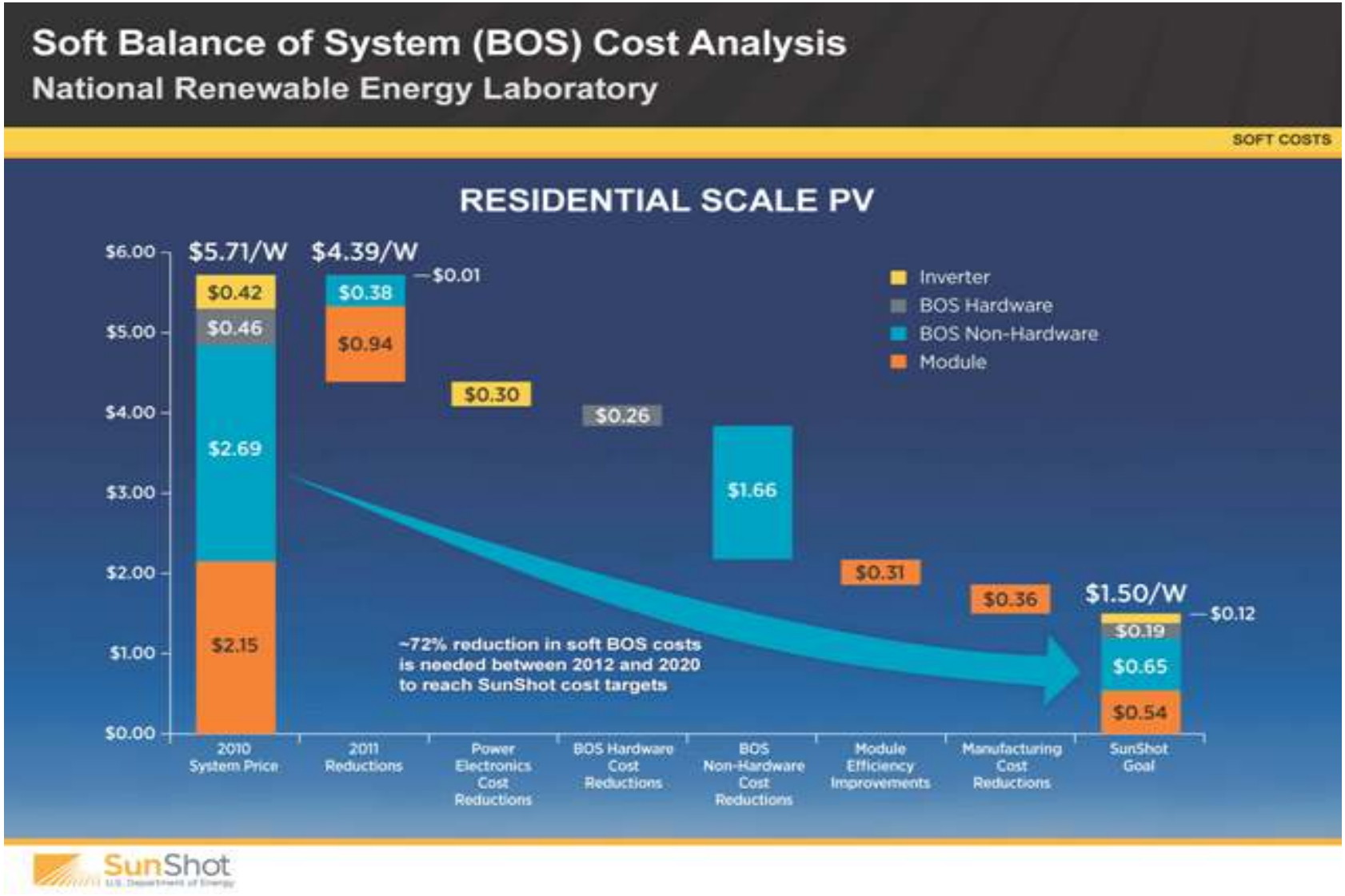


Price of PV Modules



Source: EIA 2005 data

Price of PV Systems



Costs:

- Use PERFORMANCE SPECS (kWh/year) not specific manufacture or kW.
- Provide clear requirements and evaluation criteria
- Costs depend on:
  - Size – bigger is better:
  - Balance of system costs including structures, inverters, electrical and interconnection.
- Lowest cost is direct roof attachment such as standing seam metal roof – Installed approx. $4/Wdc for 100kW
- Ballasted or racks – add $0.3/W
- Ground mount fixed tilt – add $0.35/W
- Single axis tracking (over 300 kW) – add $0.7/W
- Carports – add $0.6/W (careful w/ snow and ice)
- High efficiency modules (GT 17%) add $0.5/W

Priorities: Where to Install Solar

1. On the "Built Environment" where unshaded – size to capacity (pipes & wires) and load (kWh & thermal)
   a. **On existing building roofs that have an expected life of at least 15 more years and can accept added load. Reduces solar load on building. NEPA categorical exclusion.**
   b. On ALL new buildings – all new building should be "solar ready", see http://www.nrel.gov/docs/fy10osti/46078.pdf
   c. Over parking areas, pedestrian paths, etc. – energy generation and nice amenity.
2. On compromised lands such as landfills & brownfields.
   a. Saves green fields for nature.
3. IF installed on green fields minimize site disturbance, plant native low height vegetation as needed.

Roof Characteristics

Ideal – Install PV on new roof, require 25 year roof warranty W/ PV installed (PV comes with 25 year warranty).

Acceptable – Install PV on roof with at least a 15 year expected life.

- Roof MUST be able to accept added weight and wind load of PV – Typically 2 lbs/square ft.
- Do not install PV on lightweight roofs such as mobile homes or on roofs in poor condition.

General Solar Guidelines

- ✓ Avoid shading from trees, buildings, etc. (especially during peak sunlight hours)
- ✓ Check the zoning laws for the proposed site to ensure that future, neighboring construction will not cast shade on the array.
- ✓ Determine where a future solar array might be placed.
- ✓ If the roof is sloped, the south-facing section will optimize the system performance; keep the south-facing section obstruction-free if possible.
- ✓ Minimize rooftop equipment to maximize available open area for solar collector placement.

General Solar Guidelines

- ✓ The type of roof installed can greatly affect the cost of installing solar later.
- ✓ The roof must be capable of carrying the load of the solar equipment.
  - PV – between 2 and 6 lb/ft2
  - ST – between 2 and 5.5 lb/ft2
- ✓ The wind loads on rooftop solar equipment must be analyzed in order to ensure that the roof structure is sufficient.
- ✓ If it is going to be a rack mounted system, consider installing the mounting hardware at the time the roof is installed and use flashings for every penetration.
- ✓ If the collectors will be placed on the roof, check if the roof installation carries a warranty.
  - Determine if the roof warranty contract has terms involving solar installation.
- ✓ Make sure all equipment is in compliance with the current version of the National Electrical Code.

Additional Guidelines for PV

- ✓ Identify electrical panel location for PV system inter-connections, and keep space available in the electrical panel for a PV circuit breaker
- ✓ Specify panel capacity sufficient to accommodate proposed PV system size power generation plus size of breaker protecting main panel.
  - NEC allows for the sum of these two sources of power to be 20% greater than the panel rating. Consult the local authority having jurisdiction.
- ✓ Lay out the locations for the inverter and the balance of system (BOS) components.
- ✓ Identify the inter-connection restrictions for the location of the building site that apply to grid-tied PV systems. Begin by reviewing interconnection standards at http://www.dsireusa.org/

DSIRE™

Database of State Incentives for Renewables & Efficiency

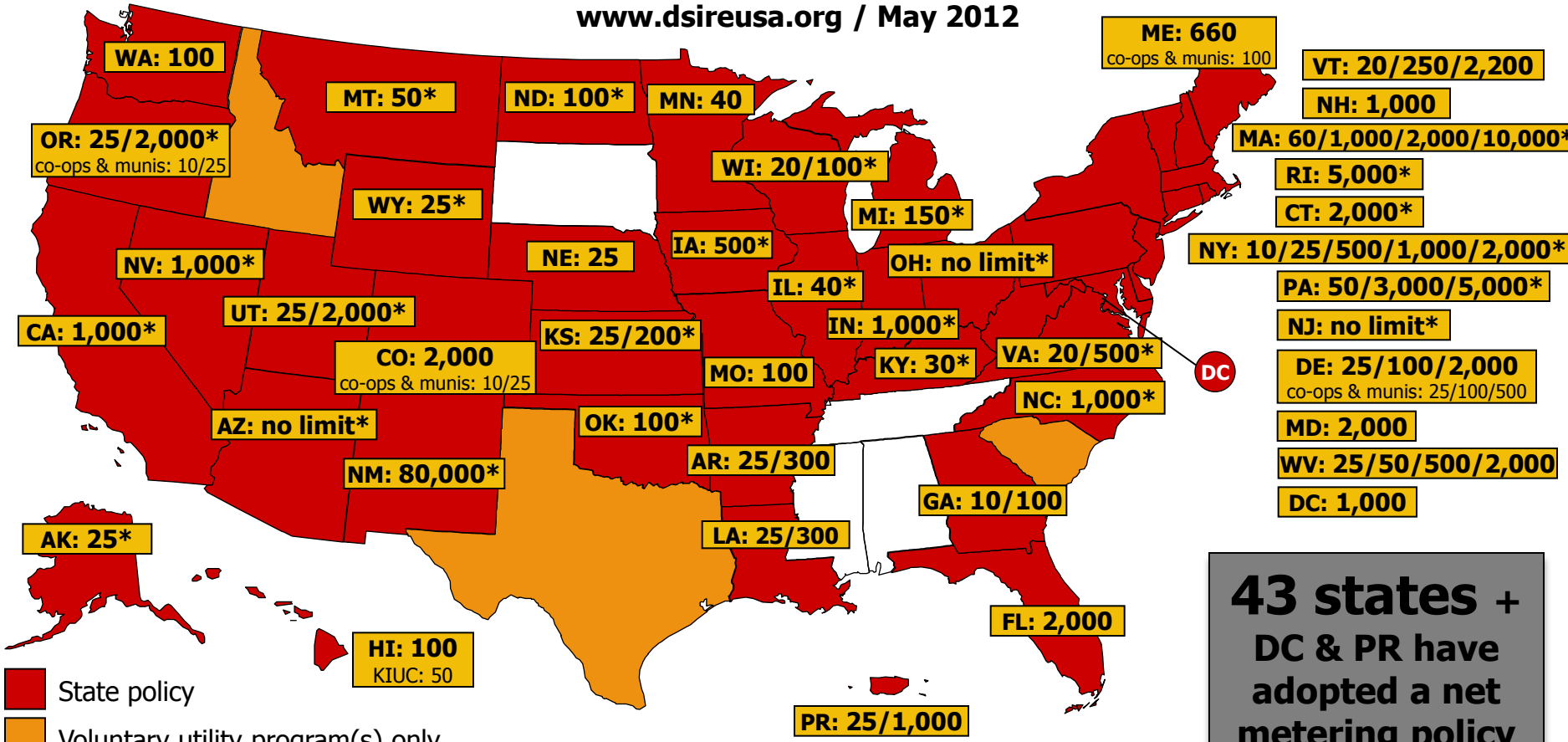
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

IREC Interstate Renewable Energy Council

North Carolina Solar Center

Net Metering

www.dsireusa.org / May 2012



43 states + DC & PR have adopted a net metering policy

State policy

Voluntary utility program(s) only

* State policy applies to certain utility types only (e.g., investor-owned utilities)

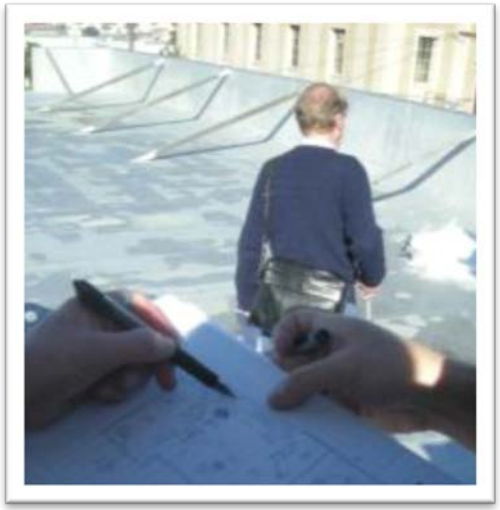
Note: Numbers indicate individual system capacity limit in kW. Some limits vary by customer type, technology and/or application. Other limits might also apply. This map generally does not address statutory changes until administrative rules have been adopted to implement such changes.

Solar Assessment – PV is VERY shade sensitive

Once site preliminary assessment has been completed.

What you want to know:

- Estimated system size
- Estimated production (kWh/yr)
- Estimated cost
- Some economic analysis



Utility Interconnection- Where to land the power?

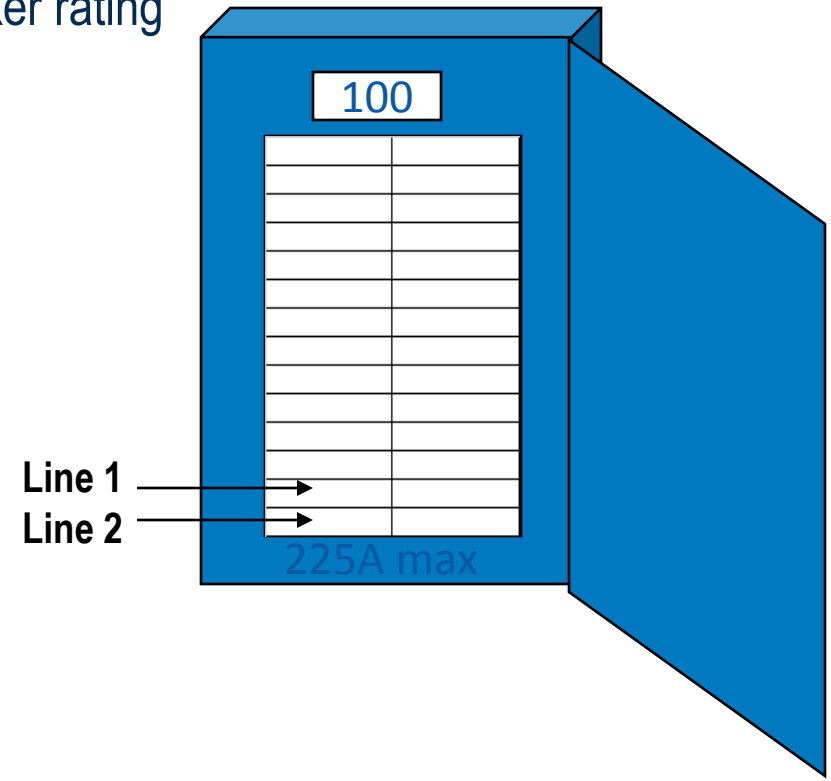
Backfeed Breaker in Building Panel (Sum of Main Breaker and PV breaker not to exceed 120% of panel rating for commercial building, 100% for residential)

Too big?- Survey Loads and reduce main breaker rating

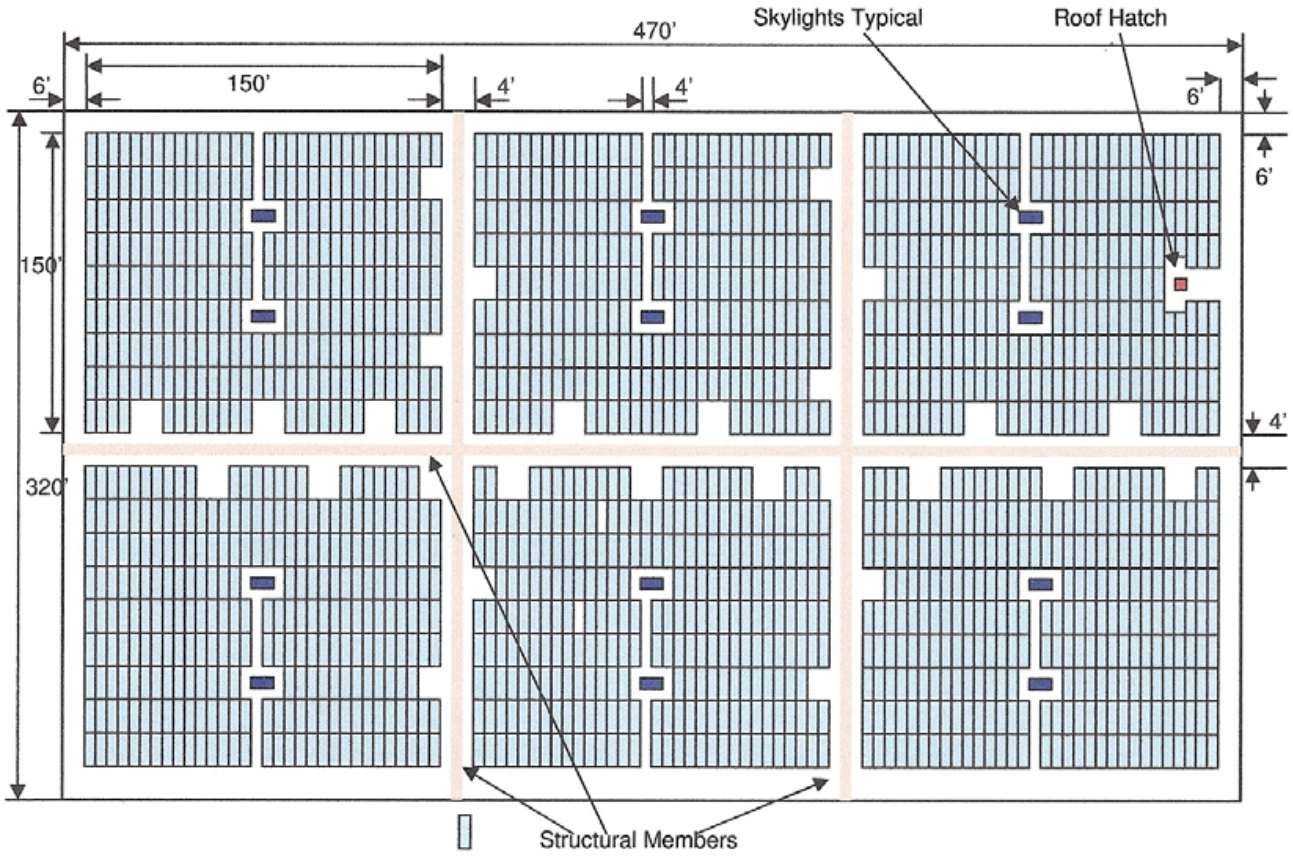
Too big?- Upgrade Panel

Too big?- Line-side-tap

Too big?- Upgrade Electrical Service

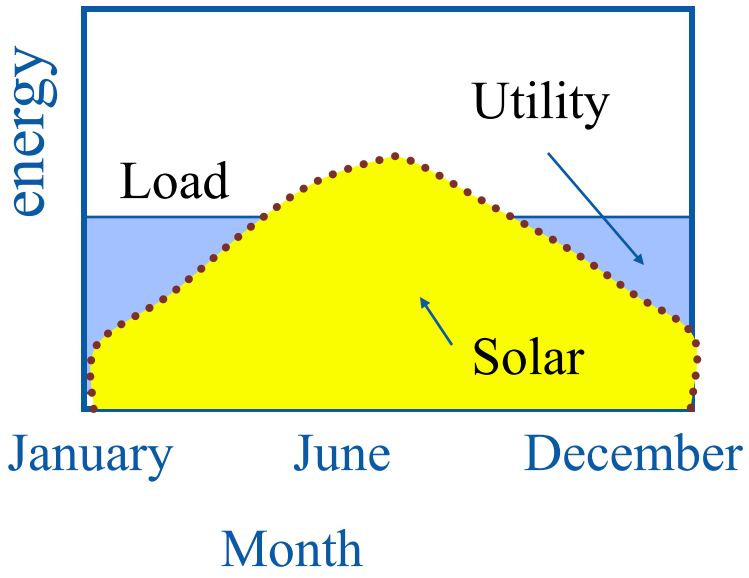


Roof Access Issues



Large Commercial Building (Axis > 250 ft)
4 ft Walkways
8 ft x 4 ft Venting Opportunities Every 20 ft Along Walkway
http://irecusa.org/wp-content/uploads/2010/10/Brooks-Fire-Guidelines-Webinar-Nov2010.pdf

PV System Size and Energy Delivery
Net Zero on Annual Average Basis



Solar System Size

$$P_{rated} =< \frac{L}{\eta_{bos} I_{ave}}$$

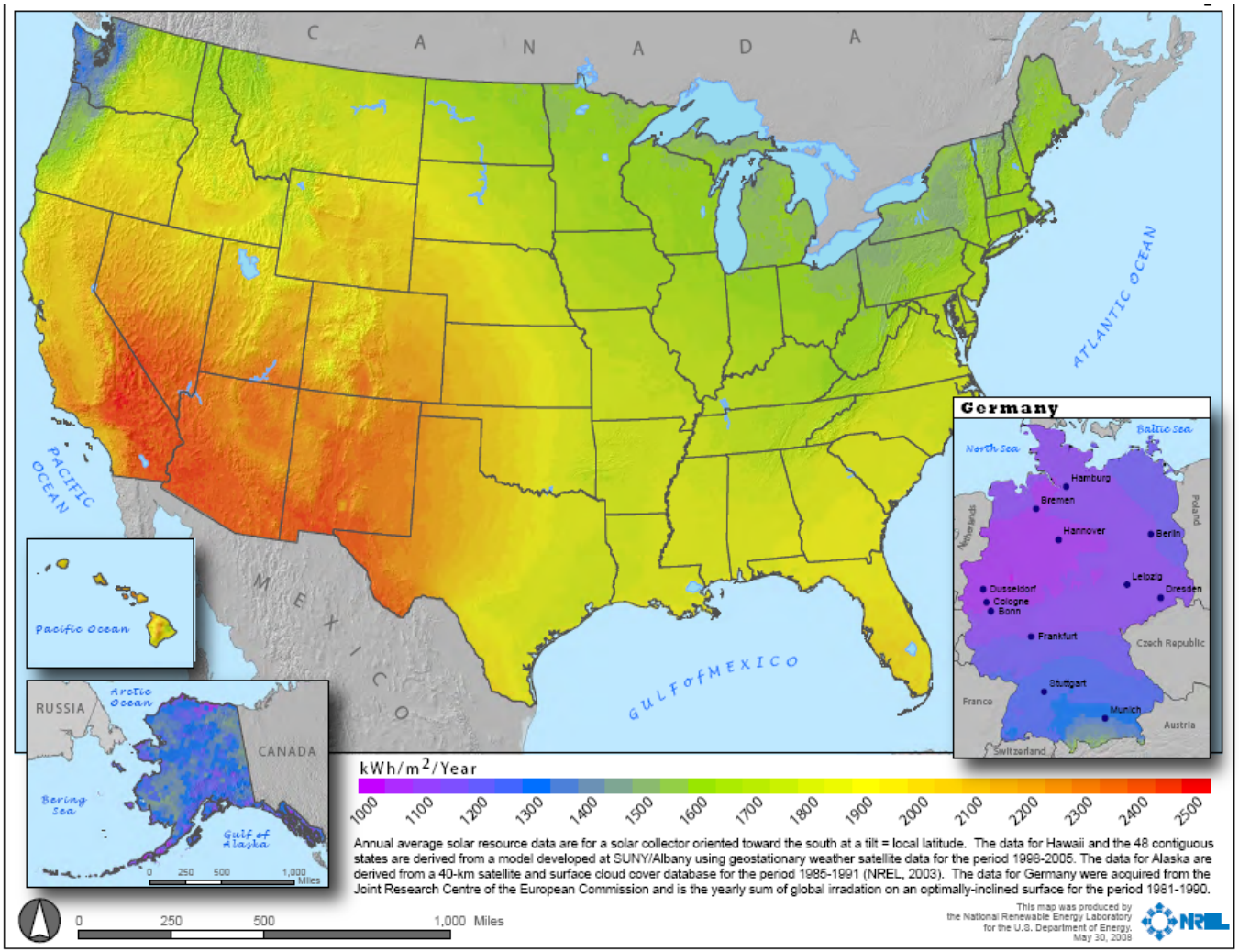
P_{rated} = rated PV power (kW)
L = Daily Load on PV (kWh/day)
I_{ave} = average daily solar radiation (sun hours/day)

Annual Electricity Generation

$$E_{gen} = P_{rated}\, \eta_{bos} I_{ave}\, 365$$

η_{bos} = balance of system efficiency, typically 0.77

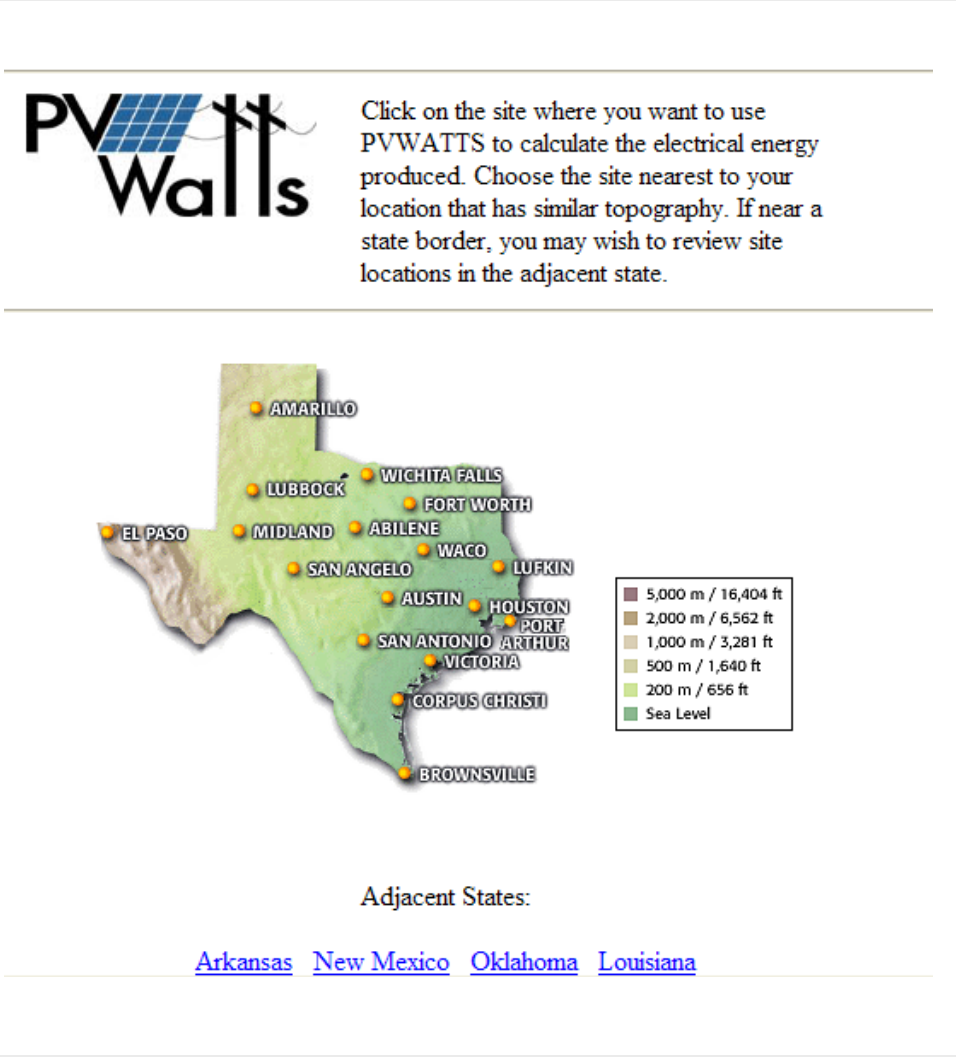
U.S. & Germany Comparison


CANADA
MEXICO
PACIFIC OCEAN
ATLANTIC OCEAN
GULF of MEXICO
Pacific Ocean
RUSSIA
Arctic Ocean
CANADA
Bering Sea
Gulf of Alaska
0 250 500 1,000 Miles
Germany
Baltic Sea
North Sea
Hamburg
Bremen
Hannover
Berlin
Netherlands
Poland
Dusseldorf
Cologne
Bonn
Leipzig
Dresden
Frankfurt
Czech Republic
Stuttgart
France
Munich
Austria
Switzerland
kWh/m2/Year
1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500
Annual average solar resource data are for a solar collector oriented toward the south at a tilt = local latitude. The data for Hawaii and the 48 contiguous states are derived from a model developed at SUNY/Albany using geostationary weather satellite data for the period 1998-2005. The data for Alaska are derived from a 40-km satellite and surface cloud cover database for the period 1985-1991 (NREL, 2003). The data for Germany were acquired from the Joint Research Centre of the European Commission and is the yearly sum of global irradiation on an optimally-inclined surface for the period 1981-1990.
0 250 500 1,000 Miles
This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. May 30, 2008
NREL

	Germany	USA
Pop. (2006)	82 M	298 M
Pop. Density (per/km^2)	230	31
Annual electricity use per capita - MWh (2006)	6.4	12.5
Average electrify rate ¢/kWh (2006 USD)	22.2	10.4 (ranges from 5-17)
Total Installed W_p per capita (2009)	~100	~5

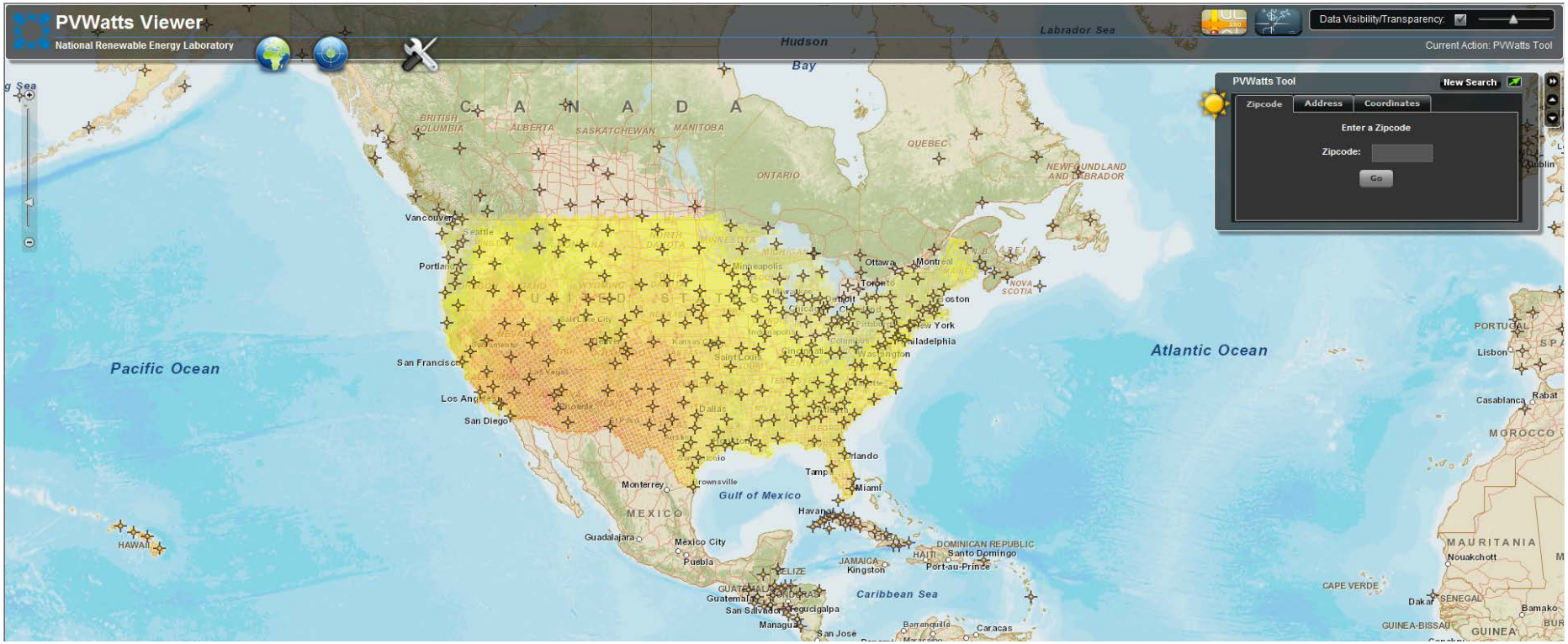
PV Watts

- **PV Watts v1 and v2**
  - Photovoltaic Analysis
  - Select default values *or* input customized system parameters for size, electric cost, array type, tilt angle, and azimuth angle
  - Typical Meteorological Year weather data for the selected location (TMY files) used to calculate incident solar radiation and PV cell temperature for each hour of the year
- **Benefits**
  - Easy to use
  - Very Quick
  - Useful for users of all technical levels
  - Widely accepted tool

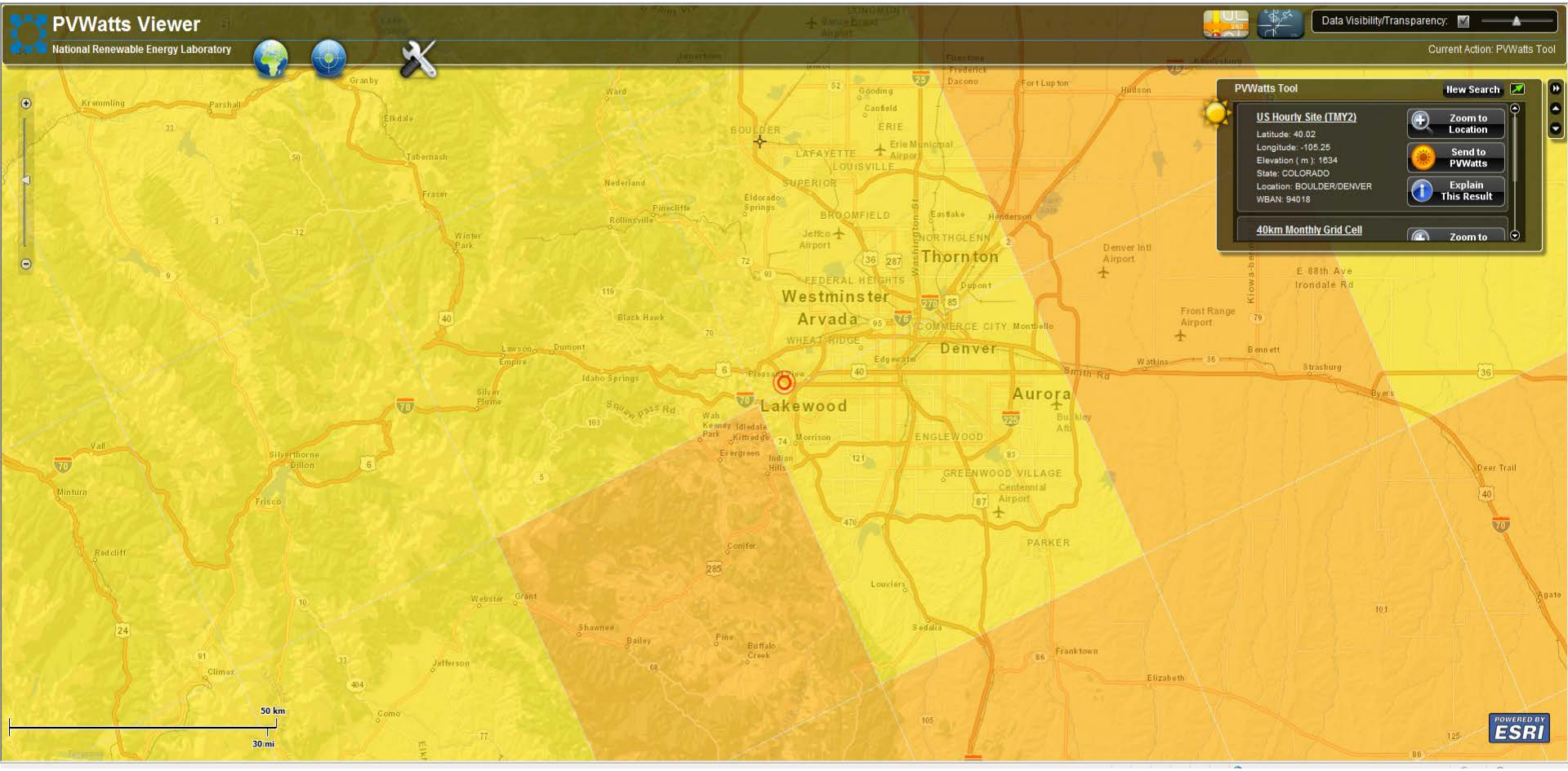


PV Watts v2

- Flex Viewer - http://gisatnrel.nrel.gov/PVWatts_Viewer/index.html
- Solar Grid Data (40 km grid)
- Send the location data to PVWatts v2



PV Watts v2


PVWatts Viewer
National Renewable Energy Laboratory
Data Visibility/Transparency:
Current Action: PVWatts Tool
PVWatts Tool
New Search
US Hourly Site (TMY2)
Latitude: 40.02
Longitude: -105.25
Elevation (m): 1634
State: COLORADO
Location: BOULDER/DENVER
WBAN: 94018
Zoom to Location
Send to PVWatts
Explain This Result
40km Monthly Grid Cell
Zoom to
Thornton
Westminster
Arvada
Denver
Aurora
Lakewood
Boulder
Golden
Broomfield
Lafayette
Louisville
Superior
Erie
Northglenn
Federal Heights
Wheat Ridge
Commerce City
Englewood
Greenwood Village
Parker
Idaho Springs
Evergreen
Conifer
Black Hawk
Central City
Nederland
Golden
Denver Intl Airport
Front Range Airport
Centennial Airport
50 km
30 mi
POWERED BY ESRI

PV Net Zero Energy Home Example in Boulder, CO

- Annual Energy use = 6000 kWh
- PV on south facing roof sloped at 20 degrees produces 1458 kWh/kW Annual with 0.8 derate factor
- 6000 kWh/1458kWh/kW = 4.1 kW
- Expected cost at $4/W = $16.4K before incentives
- Area required = 4100 W/11W/sq ft = 373 sq ft.

IMBY

- **In My Backyard (IMBY)**
  - Use a cursor to track the area outline, tool returns the feasible system size
  - Looks up incentives, rebates, system costs
  - Runs the production calculation using PVWatts v1
- **Benefits**
  - Calculates system size for the user
  - Quick PVWatts calculation run time
  - Interactive, and allows the user to modify all calculated values

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

RETScreen International

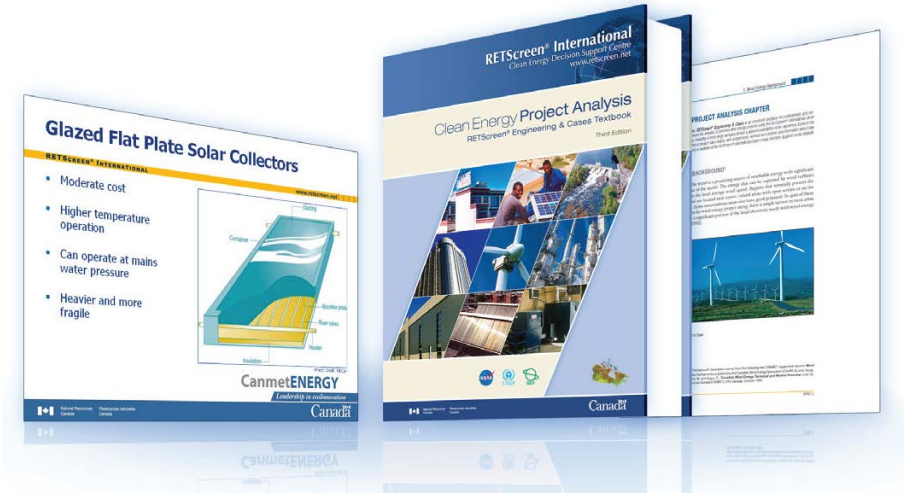
- Excel based integrated worksheets that run a suite of EE and RE technologies
  - Photovoltaic
  - Solar Thermal
  - Wind
  - Small Hydro
  - Biomass
  - Ground Source Heat Pump
  - Combined Heat & Power (CHP)
  - Energy Efficiency

Natural Resources Canada | Ressources naturelles Canada

RETScreen

Five Step Standard Analysis

- Energy Model
- Cost Analysis
- Emissions Reduction
- Financial Analysis
- Sensitivity & Risk Analysis



Benefits

- Comprehensive Training Resources
- On-line webcasts, presentations, instructor notes
- Case studies, assignments, worked-out solutions
- Detailed user manual
- e-textbook
- Clean Energy Legal Toolkit

Free Download

- http://www.retscreen.net/

System Advisor Model

Sophisticated software tool that can run very detailed RE models

- Photovoltaics
- Solar Hot Water
- Concentrating Solar Power
- Small Wind
- Large Wind
- Geothermal Power

System Advisor Model (SAM)

Detailed Economic Models

- Cost of generating electricity (LCOE)
- Type of financing
- Applicable tax credits and incentives
- Can model variety of rate structures

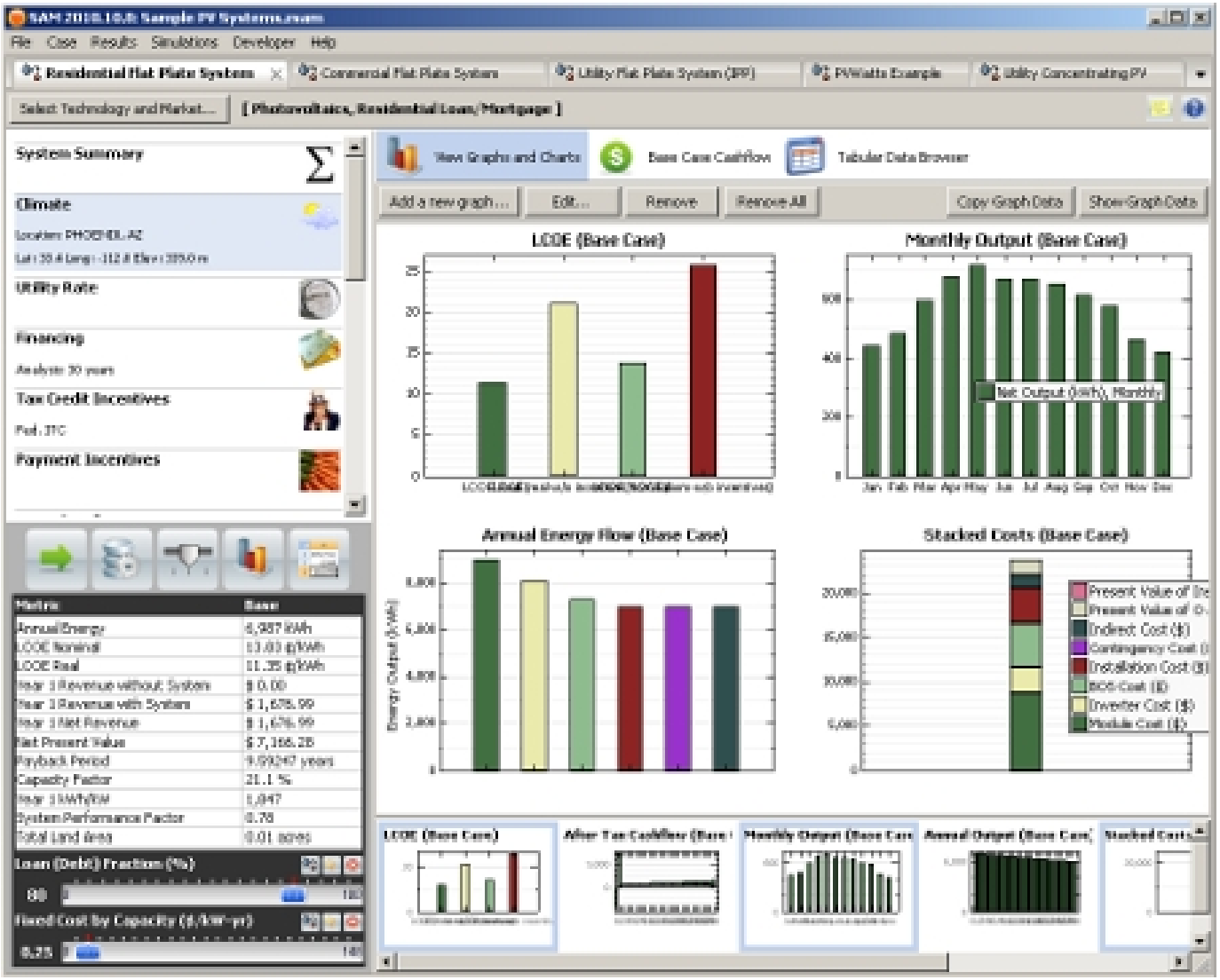
Benefits

- TRNSYS calculation engine
- Flexible ways to display data
- Can run basic models, or component based models
- Full time user support and development team
- Capable of running parametric simulations

Free download

- https://www.nrel.gov/analysis/sam/

SAM


File Case Results Simulations Developer Help
Residential Flat Plate System
Commercial Flat Plate System
Utility Flat Plate System (IPP)
PVWatts Example
Utility Concentrating PV
Select Technology and Market...
[Photovoltaics, Residential Loan, Mortgage]
System Summary
Climate
Utility Rate
Financing
Tax Credit Incentives
Payment Incentives
View Graphs and Charts
Base Case Cashflow
Tabular Data Browser
Add a new graph...
Edit...
Remove
Remove All
Copy Graph Data
Show Graph Data
LCOE (Base Case)
Monthly Output (Base Case)
Net Output (kWh), Monthly
Annual Energy Flow (Base Case)
Stacked Costs (Base Case)
Metric
Base
Annual Energy
6,987 kWh
LCOE Nominal
13.03 ¢/kWh
LCOE Real
11.35 ¢/kWh
Year 1 Revenue without System
$ 0.00
Year 1 Revenue with System
$ 1,676.99
Year 1 Net Revenue
$ 1,676.99
Net Present Value
$ 7,166.28
Payback Period
9.09247 years
Capacity Factor
21.1 %
Year 1 kWh/kW
1,047
System Performance Factor
0.78
Total Land Area
0.01 acres
Loan (Debt) Fraction (%)
80
Fixed Cost by Capacity ($/kW-yr)
8.25

Resources

- **Solar Energy Resources**
  - NREL http://www.nrel.gov/rredc/
  - Firstlook: http://firstlook.3tiergroup.com/
  - TMY or Weather Data
    http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

- **State and Utility Incentives and Utility Policies**
  - http://www.dsireusa.org

- **Solar PV Analytical Tools**
  - Solar Advisor Model (SAM): https://www.nrel.gov/analysis/sam/
  - HOMER: https://analysis.nrel.gov/homer/
  - PVWatts: http://www.nrel.gov/rredc/pvwatts/
  - RETScreen: http://www.retscreen.net/
  - IMBY: http://www.nrel.gov/eis/imby/

Questions?

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